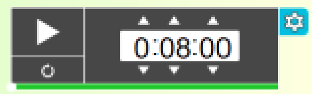
Electric fields	**Charged particles in uniform electric fields**

Learning objectives	**MUST (C)**	Recall how to calculate the force on charged particles in a uniform electric field
	SHOULD (B)	Explain how the motion of a charged particle is affected by a uniform electric field
	COULD (A/A*)	Apply the equations of motion to calculate charged particle trajectories

STARTER:

1. A student uses square plates with a side of 10 cm, separated by paper with a thickness of 0.08 mm. What is the capacitance?
2. Parallel plates with an area of 6 cm^2 are separated by a 1 mm layer of an unknown insulator. The capacitance is 5 nF. What is the relative permittivity of the material?



Side = 10 cm = 0.1 m so A = 0.01 m^2

$$C = \varepsilon_r \varepsilon_o \frac{A}{d}$$

$$= \frac{4 \times 8.85 \times 10^{-12} \times 0.01}{(0.08 \times 10^{-3})} \quad (\textit{1 mark})$$

$$= \frac{35.4 \times 10^{-14}}{0.08 \times 10^{-3}}$$

$= 442.5 \times 10^{-11}$ F

$= 4.43 \times 10^{-9}$ F or 4.43 nF (to three significant figures) (*1 mark*)

6 cm^2 = 6×10^{-4} m^2

$$C = \varepsilon_r \varepsilon_o \frac{A}{d}$$

$$\varepsilon_r = \frac{Cd}{\varepsilon_o A}$$

$$= \frac{5 \times 10^{-9} \times 1 \times 10^{-3}}{8.85 \times 10^{-12} \times 6 \times 10^{-4}} \quad (\textit{1 mark})$$

$$= \frac{5 \times 10^{-12}}{5.31 \times 10^{-15}}$$

= 941.6196

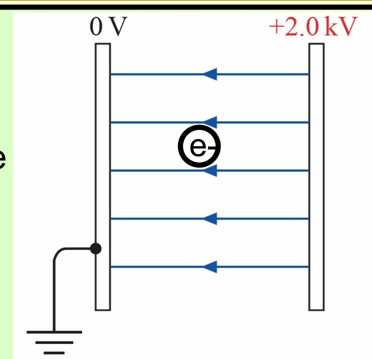
= 942 (three significant figures) NB no units (*1 mark*)

Oct 16-21:59

Electric fields	**Charged particles in a uniform electric field**
MUST (C)	Recall how to calculate the force on charged particles in a uniform electric field

What can you say about the:

1. Electric field strength between the plates?
2. The force on the electron as if moves between the plates?
3. The acceleration?



Do we have enough information to calculate any of the above? If not, what more do we need?

The electric field is uniform, and therefore the force and the acceleration are both constant.

Evaluate the two equations for electric field strength to find an expression for the force on a charged particle.

$E = F/Q$ $E = V/d$

$F/Q = V/d$

Therefore, $F = QV/d$

For an electron, this will be $F = eV/d$

Electric fields	**Charged particles in uniform electric fields**
SHOULD (B)	Explain how the motion of a charged particle is affected by a uniform electric field
COULD (A)	Apply the equations of motion to calculate charged particle trajectories

In a uniform electric field, the force on a particle is constant and so therefore the acceleration will be constant too.

We can use this acceleration in any of the suvat equations.

$$v = u + at$$

$$s = ut + {}^{1}\!/_{2}\, at^2$$

$$v^2 = u^2 + 2as$$

Example 1: An electron is fired from a positive capacitor plate towards the negative plate along the direction of the electric field, with a velocity of $1.0\text{x}10^7$ ms^{-1}.
The p.d across the plates is 600V and their separation is 3.0cm.

Show that the maximum distance moved from the positive plate is 1.4cm.

When you have done this, move on to summary questions for section 22.4.

Remember: E = V/d

F= EQ

Work done on a charged particle = Vq

$$v = u + at$$

$$s = ut + {}^{1}\!/_{2}\, at^2$$

$$v^2 = u^2 + 2as$$

1 The proton will be attracted towards the negative plate (or away from the positive plate).

The proton moves in the direction of the electric field.

It experiences a constant force and hence will have a constant acceleration between the plates.

2 The maximum kinetic energy of an electron = Ve.

Hence the only factor that affects the maximum speed of the electron is the p.d. V between the plates.

3 $KE = Ve = \frac{1}{2}mv^2$ [1]

$v = \sqrt{\frac{2Ve}{m}} = \sqrt{\frac{2 \times 1.5 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}}$ [1]

$v = 7.26 \times 10^5\ \text{m s}^{-1} \approx 700\ \text{km s}^{-1}$ [1]

4 a $E = \frac{V}{d} = \frac{2.5 \times 10^3}{0.020} = 1.25 \times 10^5\ \text{V m}^{-1}$ [1]

$v_v = \frac{EQL}{mv} = \frac{1.25 \times 10^5 \times 1.6 \times 10^{-19} \times 0.20}{1.7 \times 10^{-27} \times 5.0 \times 10^6}$ [2]

$v_v = 4.71 \times 10^5\ \text{m s}^{-1} \approx 4.7 \times 10^5\ \text{m s}^{-1}$ [1]

b $a = \frac{F}{m} = \frac{EQ}{m} = \frac{1.25 \times 10^5 \times 1.6 \times 10^{-19}}{1.7 \times 10^{-27}}$ [1]

time spent in field $= \frac{0.20}{5.0 \times 10^6}$ [1]

$s = \frac{1}{2}at^2 = \frac{1}{2} \times \frac{1.25 \times 10^5 \times 1.6 \times 10^{-19}}{1.7 \times 10^{-27}} \left(\frac{0.20}{5.0 \times 10^6}\right)^2$ [1]

$s = 9.4 \times 10^{-3}\ \text{m}\ (9.4\ \text{mm})$ [1]

Oct 16-21:59

Electric fields	**Charged particles in uniform electric fields**

Learning objectives	**MUST (C)**	Recall how to calculate the force on charged particles in a uniform electric field
	SHOULD (B)	Explain how the motion of a charged particle is affected by a uniform electric field
	COULD (A/A*)	Apply the equations of motion to calculate charged particle trajectories

PLENARY: An electron enters a uniform electric field that will accelerate it (against the direction of line of force). The initial velocity is 10 kms^{-1} and the electric field strength is 20 Vm^{-1}.

a) What is the acceleration of the electron?

b) What (to the nearest km/s) will the velocity be when the electron has travelled 9 cm in the field?

c) How long will this take?

$e = 1.6 \times 10^{-19}$ C

$m_e = 9.11 \times 10^{-31}$ kg

a) $F = eE$

$F = 1.6 \times 10^{-19} \times 20 = 3.2 \times 10^{-18}$ N

$F = ma$, therefore $a = F/m$

$a = 3.2 \times 10^{-18}/9.11 \times 10^{-31} = 3.5 \times 10^{12} ms^{-2}$

b) $v^2 = u^2 + 2as$

$v^2 = 10000^2 + 2 \times 3.5 \times 10^{12} \times 0.09$

$v = 793788\ ms^{-1}$, or $794\ kms^{-1}$.

c) $v = u + at$ rearranges to $t = (v-u)/a$

$t = (793788-10000)/3.5 \times 10^{12}$

$t = 2.239 \times 10^{-7}$ seconds

Oct 16-21:59

Aug 25-07:10